

**SYSTEM AND METHOD FOR MANAGING A PLURALITY OF
LOCATIONS OF INTEREST IN 3D DATA DISPLAYS (“Zoom Context”)**

CROSS REFERENCE TO OTHER APPLICATIONS

- 5 This application claims the benefit of United States Provisional Patent Applications 60/505,345, 60/505,346 and 60/505,344, each filed on November 29, 2002, and all under common assignment herewith.

- 10 This application is related to “METHOD AND SYSTEM FOR SCALING IN 3D DISPLAYS (“Zoom Slider”), filed on December 1, 2003, Luis Serra, Inventor, the specification of which is hereby incorporated herein by reference. Said application will be referred to herein as the “Zoom Slider” application.

FIELD OF THE INVENTION

- 15 The present invention relates to the field of interaction with computer models in three dimensions, wherein objects are displayed to a user for interaction with them. More precisely the present invention relates to managing of multiple detailed viewing sites in such a display.

BACKGROUND OF THE INVENTION

- 20 A three-dimensional (3D) *model* is a data set associating spatial coordinates (u, v, w) in *model space* with values to be displayed to a user by a *shader* in such a way that the resulting colors or other sensory qualities shown appear to a user localized at

corresponding locations. Typically, relative to the *display* coordinates (x, y, z) , which may be chosen relative to a user's apparent point of view, the model space has a *position* giving the correspondence. Most often the correspondence is specified as a matrix relationship

$$5 \quad \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} a_1^1 & a_1^2 & a_1^3 \\ a_2^1 & a_2^2 & a_2^3 \\ a_3^1 & a_3^2 & a_3^3 \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}, \text{ equivalently } \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} a_1^1 & a_1^2 & a_1^3 & X \\ a_2^1 & a_2^2 & a_2^3 & Y \\ a_3^1 & a_3^2 & a_3^3 & Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ w \\ 1 \end{bmatrix},$$

or $\mathbf{x} = \mathbf{A}\mathbf{u}$ for short, sometimes using a non-linear transformation rather than one that can be represented by a matrix. In general, an application's user interface provides many ways to modify the relation \mathbf{A} , which are experienced by a user as rotating, moving, warping or deforming the displayed model or models. A model may be a
 10 grid of scanned density or other values from, for example, a computerized tomography (CT) or magnetic resonance (MR) scan, from seismography, or from numerous other sources of such data which attach numbers to each of a regular grid of points in space. As well, such a model may equally contain a list of lines, polygons, algebraic or analytic surfaces, *etc.*, which represent a geometric form (such geometric
 15 form often being described by yet a further system of 'object' coordinates (q, r, s) , whose position in model space is described by another transformation, such as, for example, $\mathbf{u} = \mathbf{B}\mathbf{q}$), together with quantitative properties distinct from position that may vary from point to point. (Often in a given application such properties may consist of, or be represented as, for example, color and transparency data.) In all
 20 such cases a shader uses the model data together with auxiliary information about lighting, rules for what is to be transparent, modification of colors to distinguish significant value ranges, *etc.*, to create an apparent 3D image, often in stereo (using

one or more means to arrange that a user's two eyes each see slightly different views, from which a user's visual system can construct a sensation of depth).

In interacting with such models it often arises that a user must pay attention to a particular smaller *detail region* within the model space, wherein one or more of the models displayed therein have significant features. Often such detail region is displayed at a greater magnification (utilizing the techniques, for example, as described in the Zoom Slider application), a higher resolution, or in some other manner which would exhaust a system resource if applied to the display of the entire model. (Such as, for example, the fact that magnification of the entire model would move parts of it beyond the display window, thus requiring unavailable display area for full display; or a requirement of more closely spaced sampling of the data, or anti-aliasing, or shading with scattered light, *etc.*, may require more computation time between successive views than is compatible with a smooth apparent rotation of viewpoint, *etc.*).

Particularly where models include scanned volume data, it can be laborious to select a detail region. The particular display software, or a user, may standardize the size of detail regions in general, but the useful location of each particular region varies with the data set, as, for example, tumors differently located in different brains, and with a user's concerns, as, for example, vessel anatomy as opposed to bone fracture details. A user must choose the position of its center, or some other convenient anchoring point. Moreover, even in a stereo display system a user's sense of what data feature occurs at what depth may be limited in precision, particularly, as is common in

rendering volume data, inasmuch as some regions are rendered so as to appear neither transparent nor opaque, but translucent. Choosing a specific significant point may involve cropping the display to remove obscuring data, rotating its apparent position for a more revealing view, and other laborious maneuvers. While in a fully

5 interactive 3D display environment it is somewhat easier to move a selected point in the display (merely drag and drop it in any direction with a displayed stylus , experienced as being locked to a physical device held in the hand), in a mouse-and-mousepad interface even the simple modification of a model point's location is a multi-step process. A common solution for such 2D interfaces is to present a user

10 with a 'main window', which shows (a) a perspective view from the direction chosen to provide the most revealing possible view, usually parallel to no axis, and (b) subsidiary windows showing parallel views from the (x, y) , (x, z) and/or (y, z) directions separately. Moving the cursor to one of these subsidiary views directs user input (such as that provided, for example, via a mouse, trackball, or other relative

15 spatial movement based input peripheral) to control of the corresponding coordinates, and a user can watch an object or 3D cursor move both in the subwindow and the main window.

To adjust any (x, y, z) position in display space thus requires two or more successive

20 operations in such windows, while aiming for a target more clearly visible in the main window. It takes longer than a single movement, and occupies a great fraction of the scarce display space available (thus reducing detail in the main window). Rotation of the view is similarly more complex.

Moreover, even in a fully interactive 3D display environment the specification of a region of interest is an effort that it benefits a user to minimize, much more so in an environment where only 2D user display control is available. In particular, many applications require a user to select a detail region for some specific work such as, for
5 example, by assigning or modifying points in several models that — if the models were exactly aligned — would be located at the same point (u, v, w) in model space, then to select one or more others, and then return once again to the earlier selected detail regions for refinement of the initial work. It can become very time-consuming to repeat, on each return to a given detail region, the navigation interactions that were
10 needed to arrive and orient such region of interest the first time.

Objects of the present invention can include reducing this load on a user managing multiple viewing sites and facilitating a user's ability to interact with computer models.

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SUMMARY OF THE INVENTION

A system and method of presentation of 3D data sets in a 3D display is presented. In exemplary embodiments according to the present invention the method involves displaying data in an overview mode wherein localization markers can be set and
20 manipulated, and in a local mode wherein data surrounding a localization marker can be rendered using different display parameters. In exemplary embodiments according to the present invention the mode in which data is displayed can be selected by a user. In preferred exemplary embodiments according to the present invention the method

can be implemented recursively, such that within local mode sub-localization markers
 can be set and manipulated, and data can be displayed in a sub-local mode wherein
 data surrounding a sub-localization marker can be rendered using display parameters
 which can be different from both those of an overview display mode and those of a
 5 local display mode.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows an exemplary 3D model displayed within an exemplary crop box
 according to an exemplary embodiment of the present invention;

Fig. 2 shows the model of Fig. 1 with a movable 3D cursor and localization markers
 10 set at various points according to an exemplary embodiment of the present invention;

Fig. 3 shows an exemplary set of icons which may be used to denote the location of a
 localization marker point according to an exemplary embodiment of the present
 invention;

Fig. 4 shows an exemplary 3D model displayed with box type icons representing
 15 detail regions, each superimposed on the model without regard to opacity according to
 an exemplary embodiment of the present invention;

Fig. 5 shows the model and boxes of Fig. 4, displayed with regard to opacity
 according to an exemplary embodiment of the present invention;

Fig. 6 is an exemplary modular software diagram according to an exemplary
 20 embodiment of the present invention;

Fig. 7 is a process flow diagram according to an exemplary embodiment of the
 present invention;

Figs. 8- 15 depict an example application of precise measurement of distances according to an exemplary embodiment of the present invention; and

Fig. 16-23 depict an example application of precise insertion of markers according to an exemplary embodiment of the present invention.

5 DETAILED DESCRIPTION OF THE INVENTION

A 3D data display operates in two modes, *local* and *overview*. In overview mode, the display of a model space is accompanied by the display of a number of localization markers. In this mode a user may add new markers, delete existing ones, and select or move a currently active one. Such markers have positions which are fixed relative to
 10 the model space. In an exemplary embodiment the markers remain visible to a user even where their location would normally be obscured by opaque shading.

In local mode, the detail region surrounding an active localization marker is displayed using different display parameters than those used in overview mode, such as, for
 15 example, to provide some type of greater or alternative detail. Such detail may include, for example, the use of higher resolution, more computation-expensive rendering techniques, or a larger scale (zoom). In the case of, for example, zoom, no part of the display outside of the detail region is rendered so as to obscure a user's view of the enlarged detail region. To achieve this, the display outside of region may
 20 be subject to additional cropping, or not be rendered at all. As well, the zoomed view may be centered on a standard convenient point in the display region, be centered on the display point indicated by the chosen localization marker, or even move from one to the other.

Local and overview modes are defined relative to the currently active display parameters. Thus, if the general view is, for example, enlarged, the display of a detail region is enlarged by the same factor, where possible within system resources.

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In exemplary preferred embodiments the method can be used recursively, so that within a given detail region additional sub-localization markers may also be specified. In such exemplary embodiments the same user actions that cause transition from overview to local mode also cause transition from the current local mode to a sub-
10 local mode, with new zoom, addition of detail, or display parameters used in the sub-detail region displayed around a given sub-localization marker.

The methods of the present invention are implementable in any 3D data display system, such as, *e.g.*, a volume rendering system. In general, a volume rendering
15 system allows for the visualization of volumetric data. Volumetric data are digitized data obtained from some process or application, such as MR and CT scanners, ultrasound machines, seismic acquisition devices, high energy industrial CT scanners, radar and sonar systems, and other types of data input sources. One of the advantages of volume rendering, as opposed to surface rendering, is that it allows for the
20 visualization of the insides of objects.

One type of such 3D data display system is what is referred to herein as a fully functional 3D data display environment (such as, *e.g.*, that of the Dextroscope™

system of Volume Interactions Pte Ltd of Singapore, the assignee of the present application). Such systems allow for three-dimensional interactivity with the display. In such systems a user generally holds in one hand, or in each hand, a device whose position is sensed by a computer or other data processing device. As well, the

5 computer monitors the status of at least one control input, such as, *e.g.*, a button, which a user may click, hold down, or release, *etc.* Such devices may not be directly visible to a user, being hidden by a mirror; rather, in such exemplary systems, a user sees a virtual tool (a computer generated image drawn according to the needs of the application) co-located with the sensed device. In such exemplary systems the

10 locational identity of a user's neuromuscular sense of the position of the held device, with a user's visual sense of the position of the virtual tool is an interactive advantage.

In exemplary embodiments, at any time the system contains a current specification of the enhancements to be used in viewing each detail region, such as, for example,

15 preferred scale changes, changes of resolution or sampling step, or the use of anti-aliasing. These may be preset with default values, or alternatively be modifiable by a user via, for example, a system of menus, voice commands, sliders or other interaction means as may be known in the art.

20 Via an input signal, such as, for example, a menu selection, voice command, or other interaction, a user directs the system to enter the overview mode. In this mode, as illustrated in Fig. 1, all or part of the currently active model or models 101 are displayed within the current crop box 102, as determined by previous interactions between a user and the system, at the current scale and viewing position. At any point

prior to or during entry into overview mode a user may invoke other methods to change the scale, move or rotate the crop box 102 and with it the viewed part 101 of the model(s), or modify the size or position of the crop box relative to the model space, thus changing the visible portion of the model or models displayed.

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As well, in overview mode, as depicted, for example, in Fig. 2, a user moves a cursor 201 through the 3D display, by any means as may be available in a given application. This may be by 3D drag and drop in a Dextroscope™-like system, by the use of auxiliary windows in a mouse or other 2D spatially-controlled system, or by other
 10 methods as may be known in the art. When the cursor is at a point approximately central to a desired detail region, a user signals that she wishes to set or designate a localization marker. She then, for example, clicks a button on a hand-held controller such as a mouse or a 3D position sensor, issues a voice command, presses a foot pedal, or otherwise signals the system, as may be known in the art, that the active
 15 cursor position is to be set as a localization marker point 211. A marker point icon 211 is then displayed by the system fixed at that position relative to the model space.

Fig. 2 thus depicts a number of such designated localization markers. With reference to Fig. 3, such a localization marker may be displayed as, for example, a simple cross
 20 pattern 301, a pattern of triangles 302 or 303 pointing to the central point, a 3D structure with apparent solidity 304, or alternatively a box frame 305 or other structure which marks the boundaries of the selected detail region, or such other marker or combination of markers as may be useful as known in the art.

A further parameter governing detail display is the size (as a cube, or as the side lengths of a rectangular box) of the exemplary box frame 305. A user may modify this size, either in overview or in detail mode, by, for example, dragging an edge or corner of the box, as is conventional with frames and windows in a 2D environment, or by such other means as may be known in the art. Other detail region geometries such as spheres, ellipsoids, polyhedra, *etc.*, with interactive objects by which form and size may be manipulated, may be equivalently substituted within the scope of the present invention.

10 The cursor may be, for example, a stylus tip, an icon identifying a point at its center, or any other means of indicating to the user the point to be selected or moved as the center or other reference point of the detail region. In a preferred exemplary embodiment a box frame 305 is used. The user thus sees, before clicking a given point (or otherwise selecting, as may be the case in other exemplary embodiments),

15 the detail region that will result, and can thus judge what it will enclose. The orientation as well as the location of the displayed box frame cursor 305 matches that of the detail region that will be selected. Thus, if in an exemplary embodiment the system always shows a detail region with edges parallel to the model space axes, such an indicator will align itself with these axes, not rotating when the stylus turns with

20 the user's hand. Alternatively, in other exemplary embodiments where detail regions are not so restricted, a detail region indicator (including both the center of the detail region indicator as well as any detail region boundary marking indicator) may move as if rigidly attached to the stylus, rotating as the latter does. In an exemplary embodiment of such systems, the selected detail region reproduces the cursor

25 orientation current at the moment of selection, surrounded by a box frame of exactly

the same shape, size and position as the cursor at that moment. If a user wishes, for example, to create a detailed view of a straight artery section that is far from parallel to any model axis, this orientation control is of considerable value. Later dragging of the detail region can then include rotating it.

5

In exemplary embodiments an interface by which the user may modify the default shape and size of the detail region(s) selected is provided. Such an interface may comprise, for example, sliders or other interactive objects as may be known in the art.

In a preferred exemplary embodiment of the invention in a fully functional 3D environment, where both rotation and translation are easily controlled by a user's hand, these parameters (i.e., those that control shape and size of the detail region) may be manipulated by use of a box frame cursor, for example by a 'sticky point' interactive object at a standard location in the display. When a user places an edge or corner of a box frame cursor 305 near this point and signals (for example, by holding down a button) an intention to change these parameters, the respective edge or corner is constrained (until the user signals a change of intention, for example, by releasing a button) to continue to pass through or lie on the sticky point. The box frame cursor center is moved as usual by the user. As a result, pulling the cursor away from the sticky point enlarges the box, while pushing toward it shrinks it. Lateral movement may increase one side length while decreasing another, unless the box frame is constrained by the exemplary system to remain cubical. Alternate embodiments may have a variety of analogous means with which to control the parameters governing detail region size as may be desirable and as may be known in the art.

In exemplary embodiments existing localization markers may be manipulated as follows. When, in overview mode, a cursor is, for example, within a pre-set *proximity zone* of a particular localization marker, that marker becomes the *current marker* if no other is closer to the cursor. In this context a proximity zone can be defined, for example, as where a distance vector (x, y, z) between the cursor and the particular localization marker have less than a currently set threshold value, where a distance vector can be defined, for example, as $x^2 + y^2 + z^2$, as $|x| + |y| + |z|$, or as $\max(|x|, |y|, |z|)$. Once in a given marker's proximity zone, a user may enter a *dragging mode* by, for example, holding down a specified button, or by otherwise indicating such an intention as may be defined by the display system, in which mode the localization marker will move with the cursor does until a user signals an exit from such dragging mode by, for example, releasing a button or making some other appropriate sign. The existence of a current localization marker does not interfere with the placement of a new marker near it, which is simply achieved by invoking the standard user action for such placement, as described above.

Alternatively, by invoking another signal such as, for example, a double click, a right mouse click, a voice command or other appropriate interactive sign, a user may delete the current marker from the localization marker list maintained by the system. In a preferred exemplary embodiment, if the software supports a general "undo" command the issuing of this command immediately after such deletion can cause reinsertion of the deleted marker in the list.

Similarly to the proximity region used to activate drag and drop functionality near a particular marker, defined by some proximity criterion, each localization marker determines a *detail region*, such as, for example, the set of points whose distance vector (x, y, z) from the marker have $x^2 + y^2 + z^2$, or $|x| + |y| + |z|$, or $\max(|x|, |y|, |z|)$

5 less than a currently set value. When in local mode, the detail region surrounding an active localization marker is displayed using different display parameters than that used in overview mode, such as, for example, to provide some type of greater or alternative detail, as described above. One example of such greater detail that can be provided is a scale change, as described in the Zoom Slider application.

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Local and overview modes are defined relative to the currently active display parameters. Thus, if the general view is, for example, enlarged, the display of a detail region is enlarged by the same factor, where possible within system resources.

15 In an alternative exemplary embodiment, the system may additionally support a *cycling mode* in which the detailed region surrounding each localization marker in the list is displayed as a user issues a step command (by, for example, click, voice or other means as may be known in the art). In a 2D interactive system such as a mouse interface, where cursor position is controlled by relative motions, it is appropriate to

20 cause the cursor to jump to an appropriate position for dragging. A 2D mouse user is accustomed to sudden discontinuous movements of the cursor, such as, for instance, jumping to a newly appearing text entry box. Thus, a mouse-driven cursor that must appear on a detail icon to drag it should jump from each currently selected detail region to the next, saving motion on the mousepad. . In other exemplary systems a

user may expect an absolute cursor position to always correspond to the same absolute control position, such as in a Dextroscope™-like or touch screen interface, following the tool in the user's hand, with no cursor movement that does not follow the hand. In such a system, cycling behavior may desirably be omitted. The cycling
5 mode may be active concurrently with the other functionalities of overview mode.

The display of localization markers involves certain choices, which may be made differently in various alternative exemplary embodiments of the present invention. The markers 211 in Fig. 2, for example, are shown in an unobscured display, as are
10 the boxes 411 in Fig. 4. Using such a display alternative, when viewing from a single direction, it is not easy for a user to perceive their depth (i.e., the distance from a user's viewpoint). If the displayed model 101 or 401, respectively, is rendered as an opaque object, a possible perceptual default is that the marker must be nearer a user than the object it occludes. In a display system with stereo views, parallax or other
15 depth cues, a user's visual system has information that may place the perception at a greater depth, in conflict with the occlusion cue.

To address this situation, in an alternative exemplary embodiment, such as is depicted in Fig. 5, markers are hidden where they would be occluded by the model 501. This
20 presents a consistent set of depth cues to a user, but may partially or completely conceal one or more markers as a tradeoff. (Since a marker may have been originally placed when the crop box was smaller, thus exposing different parts of the model to view, or it may have been placed when a shader was in use that made more of the model transparent, a given marker may subsequently become invisible within an

opaquely rendered model from all directions.) In a preferred exemplary monoscopic display embodiment, a larger scale display structure is added to a marker, such as, for example, long lines parallel to each axis, which will thus protrude beyond an opaquely rendered model. In a preferred exemplary stereoscopic display

5 embodiment, the technique of ‘apparent transferred translucency’ can be used, as described more fully in the Zoom Slider application. In such a technique a model appears to a user to be translucent (only) with respect to light emanating from the displayed marker, thus allowing such marker — although actually occluded — to be easily seen.

10

Where an enhanced display to be used in a given detail region surrounding a localization marker involves only changes that do not change scale (such as, for example, finer resolution or anti aliasing), it may be included in the overview display. If system resources are sufficient, all detail regions may simultaneously be shown in

15 such an exemplary enhanced manner. If they are insufficient, such enhanced rendering may be restricted to the detail region centered on the current marker, and optionally include, for example, the other N detail regions last visited, where N may be a system default number or a number dynamically computed as a function of the current size of detail regions and of the enhancement options currently in force.

20

Where the enhancement to the display in a given detail region includes a change of scale, a user may signal a change to local mode by click, command or other means, in which a cursor entering the proximity zone of a given localization marker immediately causes the corresponding detail region of that marker to be displayed on

a larger scale. Such magnified display may remain centered on the same point, or may be centered on a preferred viewing point near the center of the display region. Alternatively, the system may indicate (by, for example, highlighting or otherwise) which is the current localization marker and corresponding detail region, and provide
5 an interface by which desired zoom factors can be input by a user, such as, for example, slider or voice commands. As well, in this setting the zoomed display may remain centered on the marker point, or on the preferred viewing point. Alternatively, it may slide toward the preferred viewing point as the scale is enlarged as described in the Zoom Slider application.

10

In exemplary embodiments where a change to local mode is automatically triggered simply by a cursor moving into a detail region, without any separate command signal from a user, upon cursor exit from the detail region the display returns to overview mode. Alternatively, an exemplary embodiment may make provision for a discrete
15 action to cause this effect, such as, for example, a click, voice command or other user generated signal. As well, in exemplary embodiments where a discrete user signal is used to trigger entry into local mode, a discrete signal is generally used for exit therefrom.

20 Invoking the cycling mode when a detail region is zoomed causes each detail region in turn to be displayed in a zoom mode. System settings, optionally adjustable via a user preferences interface, determine whether (a) all detail regions are displayed using as a common zoom factor that which was current when cycling was invoked; (b) whether each is to be displayed using the zoom factor which has been most recently

set for it, or (c) some other region specific zoom factor as may be determined. Similar controls determine whether all detail regions are to be displayed as centered on (a) their respective localization marker points, (b) the preferred viewing point, (c) moving from the localization marker point to the optimum viewing point as per the techniques
5 described in the Zoom Slider application, or (d) as determined by a user intervention interactive object, such as, for example, a zoom slider.

In an exemplary embodiment, in local mode, portions of the model(s) outside the detail region may remain visible to provide context. In such embodiments they are so
10 rendered so as not to obscure the enlarged view of the detail region. This may be achieved by, for example, clipping the overview display to render invisible those parts of the model that are at a lesser depth than the current marker point, or some equivalent functionality.

15 As well, an exemplary embodiment may include the ability to *detach* a scaled view or other modified display of a detail region, making it an additional component of the displayed scene that does not vanish when another detail region is selected. The motion controls of the system can then be applied separately to this view, to its respective crop box, such that a user may move it to a convenient place for viewing in
20 a displayed scene including other elements such as other scaled regions. In such an exemplary embodiment, moving a cursor into the detached view's crop box makes it the active region for communication with the system, determining such aspects as the mapping between cursor position (x, y, z) and model space position (u, v, w) as described above. This is useful if, for example, a user needs to define a straight line

in model space by moving one end, with the aim of arranging it such that a distant part of the line passes accurately through a particular point. This therefore requires simultaneously observing both the one end and the distant part in scaled views, often where the scale required would be incompatible (too large) with including both in a
5 common view that includes intervening points. (The alternative, a need to switch repeatedly between the two scaled views would make this a very laborious, inefficient and thus undesirable process.) The need for such geometric construction with precision at multiple points arises in many 3D applications, from the planning of surgical procedures or mines to the computer aided design (CAD) of mechanical
10 systems.

When a detail region is shown in a change of scale (zoomed) view, its localization marker point remains visible (as do any other marker points within the detail region), with the apparent size of the marker icon unzoomed. It can still be manipulated as in
15 overview mode, as can any other marker points within the region, with the result of changing the detail region and thus the displayed portion of the model or models.

In preferred exemplary embodiments, the same commands and interface(s) actions used to manipulate the localization marker in an overview mode are available in a
20 local mode.

As well, in exemplary embodiments, when in a zoomed view of a detail region a user may define new marker points, which may have model space positions (u, v, w)

which are defined either (a) absolutely or (b) relative to the localization marker point. These new localization markers may either act as new marker points sharing the common list with the current one, or act as a sub-list of marker points visible only when this detail region is active, and with smaller detail regions associated with them

5 which may themselves be further zoomed or presented in greater detail. This latter feature is less often useful when working with scanned data models (which become blurred, like 2D digital images, when greatly zoomed) than with high-precision models such as those used in CAD, where points on a machine that is meters wide may be specified with micrometric precision, and substructures may require their own

10 zoom marker families. The new localization marker points can be caused to so act either according to defined system behavior or as adjustable by user settings.

Figure 6 depicts an exemplary modular software program of instructions which may be executed by an appropriate data processor, as is or may be known in the art, to

15 implement a preferred exemplary embodiment of the present invention. The exemplary software program may be stored, for example, on a hard drive, flash memory, memory stick, optical storage medium, or other data storage devices as are known or may be known in the art. When the program is accessed by the CPU of an appropriate data processor and run, it performs, according to a preferred exemplary

20 embodiment of the present invention, a method of displaying a 3D computer model or models in a 3D data display system. The exemplary software program has four modules, corresponding to four functionalities associated with a preferred exemplary embodiment of the present invention. Numerous alternate modular software program implementations are also possible for various exemplary embodiments and preferred

25 exemplary embodiments of the invention.

The first module is, for example, a Localization Marker List Manager Module 601, which can accept user inputs via a user interface as may be known in the art, such as, for example, localization marker positions, sub-localization marker positions, detail region boundaries, detail region orientations, cropping data, *etc.*, display parameters of detail regions, (including, for example, a zoom scaling factor or certain quantitative properties to be displayed for the 3D data), all as described above, as well as user or system generated mode activation/selection signals.

A second module is, for example, a Local Mode and Recursive Display Module 602, which, once signaled by the Localization Marker List Manager Module 601 that local mode has been signaled, displays the data within the detail region and/or sub-detail region according to the display parameters associated with the detail region and/or the sub-detail region surrounding the current localization marker and/or sub-localization marker.

A third module, the Overview Mode Display Module 603 receives inputs from the Localization Marker List Manager Module 601 regarding the location of localization markers and applies the defined rules, including, for example, rules as to symbology, opacity, apparent transferred translucency, *etc.*, as described above, to display the various localization markers then maintained in the system.

A fourth module is, for example, a Cyclic and Multiple Detail Region Display Module 604, which takes data inputs from, for example, the Localization Marker List Manager Module 601, and displays the various detail regions in succession if cyclic mode is signaled, or displays multiple detail regions in the display scene in response to a detach command.

Fig. 7 depicts a process flow diagram according to an exemplary embodiment of the present invention. In the depicted exemplary embodiment, the cursor is a box frame indicator such as 305 with reference to Fig. 3. Thus, as described above, before
5 selecting a given point as a localization marker point, the user sees the detail region that will result from selecting that point, and can judge what it will enclose. The process flow diagram illustrates the process of selecting a local mode view, and interacting in local mode with the model and/or the detail region, and finally returning to overview mode. Beginning at start 701, flow passes to 702, where a cursor or
10 equivalent icon is displayed at the tip of a virtual tool with which a user can move through a 3D display. At 703 the system ascertains whether the user has selected the local mode, as described above. If "NO" process flow returns to 702. If "YES", at 704 the system enters the local mode, and accordingly displays an enlarged view of a model or models, as well as the boundaries of the detail region (or region of interest).
15 At 705 a user may manipulate the model(s), or may manipulate the boundaries of the region of interest, using, for example, a tool tip. At 706, if in 705 the region of interest's boundaries were modified, the model or models are displayed within the new boundaries of the region of interest. At 707 the system queries whether the operation should stop. If "NO" then flow returns to 705. If "YES" then flow moves
20 to 708 and terminates, returning the user to overview mode.

The following is exemplary pseudocode which can be used to implement an exemplary embodiment of the present invention.

25 **Pseudocode:**

```

class RegionControl {
// Control Object for Local Mode
public:
5   void Render_Region_Of_Interest ();

    bool StartActivate ();
    bool EndActivate ();

10   void Store_Model_Display_Settings ();
    void Restore_Model_Display_Settings ();
    void Update_Model_Display_Settings ();

15   };

    void RegionControl::Render_Region_Of_Interest ()
20   {
        // display the cursor icon
    }

    bool RegionControl::StartActivate ()
25   {
        // returns true if control is activated by means of pressing a button.
        // otherwise, returns false.
    }

    bool RegionControl::EndActivate ()
30   {
        // returns true if control is deactivated by means of releasing a button.
        // otherwise, returns false.
    }

35   void RegionControl::Store_Model_Display_Settings ()
    {
        // store the Overview Mode display settings of the computer model to be modified.
    }

40   void RegionControl::Restore_Model_Display_Settings ()
    {
        // restore the modified display settings of the computer model.
    }

45   void RegionControl::Update_Model_Display_Settings ()
    {
        // modify the display settings of the computer model.
    }

50

```

Program Entry Point:

```

55   void main ()
    {
        // Set up variables and states, create objects
        Initialization ();
60

```

```

RegionControl regionControl; // Create one Local Mode control object

while (true)
{
5   Render_Model (); // display model in Overview Mode (includes crop box, etc)

    // Display the 3D tool with cursor icon
    regionControl.Render_Region_Of_Interest ();

10   if (regionControl.StartActivate ())
    // widget 'listens' for user signal that it's wanted.
    {
        // Enter Local Mode

15        // Store the display settings of the Overview Mode for later use.
        regionControl.Store_Model_Display_Settings ();

        // Change the display settings for the model as desired
        // (i.e., list of local regions, with shared or individual
20        // scale, level of detail, crop box, etc).
        regionControl.Update_Model_Display_Settings ();
    }
    else if (regionControl.EndActivate ())
    {
25        // Exit Local Mode, go to Overview Mode
        // Restore the original Overview Mode display settings of the model.
        regionControl.Restore_Model_Display_Settings ();
    }
    }
30   Update_System (); // Execute the display and system commands.
                        // User sees desired view, with/without modified region(s).
}
}

```

35 Exemplary Implementation and Applications

To illustrate the functionalities available in exemplary embodiments of the present invention, two exemplary applications of exemplary embodiments of the present invention will next be described with reference to Figs. 8-23. The screen shots were acquired using an exemplary implementation of the present invention on a

40 Dextroscope™ 3D data set display system, from Volume Interactions Pte Ltd of Singapore. Exemplary embodiments of the present invention can be implemented on this device. Visible in the figures are a 3D object and a virtual pen controller and sometimes a virtual control palette which appears below it as well as other icons.

A. Illustration of the precise measurement of distances

Figs. 8-15 depict an exemplary embodiment of the present invention where the ability to easily shift between overview mode and local mode is used in the precise measurement of distances between points in 3D data sets.

5

Fig. 8 depicts an original object, i.e., a human skull, from a CT data set, positioned somewhere in 3D space. A user intends to measure with great precision the distance between two points within the object, but would also like to keep an overview of the data during the operation. Fig. 9 depicts a user selecting an exemplary tool. The tool has a cube box at its tip that indicates the relative size of the magnification that will take place during the measurement. The size of the cube can be adjustable. Fig. 10 depicts a user moving the tool with the cube at its tip to the area of interest, an aneurysm.

10

Fig. 11 depicts an exemplary situation where as soon as the user actuates a control function, for example, here, when a user presses a button on the tool, the display changes to a magnification view with the size indicated by the cube on the tool. At this magnification level, a user can see the desired detail, and can thus precisely position a first measurement point on one side of the object (i.e., the right side of the aneurysm from a viewer's perspective).

20

Fig. 12 depicts how when a user implements a control function, for example, by releasing a button, and thereby goes back to overview mode, he can see the first measurement point which was placed in the context of the entire 3D object or data set.

Similarly, Fig. 13 depicts a user moving the tool away from the aneurysm for an overview.

Fig. 14 depicts a user moving the tool to the other desired measurement point, and

5 Fig. 15 depicts the effect of the user pressing again the button on the tool, to return to a high magnification mode, or, generally speaking, to a “local mode.” In the depicted exemplary embodiment, the system reads out to a user the distance between the first laid measurement point and the current location of the tool tip.

10 **B. Example Illustration of Precise Insertion of Markers**

Figs. 16-23 depict a second exemplary use of the methods of exemplary embodiments according to the present invention, precise insertion of markers. The markers are, in the depicted exemplary embodiment, placed for purposes of implementing a two-
15 point registration so that data from two different scan modalities can be co-registered.

With reference to Fig. 16, a user desires to place with accuracy two 3D markers at the center of two fiducial markers on the CT data set. As seen in Fig. 16, these two fiducials are respectively located substantially on the left eyebrow and the right
20 temple of the depicted head. To implement the marker placement, the user selects a zoom tool (as described more fully in the Zoom Slider application) by virtually pushing a zoom button on the depicted virtual control palette.

Fig. 17 depicts a user moving the tool to the first fiducial marker (substantially located on the left eyebrow of the depicted head) on the skin of the patient. A cube at the tip of the tool indicates the magnification level.

5 Fig. 18 depicts the effect of a user pressing a button on the virtual tool, wherein he can see a magnified view. With reference to Fig. 19, the user, operating in a magnified view, moves the tool tip to the center of the fiducial on the surface of the patient data (i.e., the depicted head).

10 With reference to Fig. 20, in the depicted exemplary embodiment, when a marker is at the center of the desired spot (here the fiducial) as in Fig. 19, a user can release a button to place the marker, resulting in the view seen in Fig. 20, where the tool is being moved towards the other fiducial. Thus, once marker "1" has been placed, a user can proceed to place an additional marker.

15

Fig. 21 depicts a user repeating the same procedure for a second marker, where, similarly to the situation depicted in Fig. 17, the user moves the tool and associated magnification box over the second fiducial. Fig. 22 depicts a second marker being positioned, the user again operating in magnification mode. Fig. 23 depicts the

20 situation where having returned to overview mode, the placement of a second marker at the second fiducial can be seen in the larger context of the entire head.

The present invention has been described in connection with exemplary embodiments and exemplary preferred embodiments and implementations, as examples only. It

25 will be understood by those having ordinary skill in the pertinent art that

modifications to any of the embodiments or preferred embodiments may be easily made without materially departing from the scope and spirit of the present invention as defined by the appended claims.